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Urban Heat and Wildfire

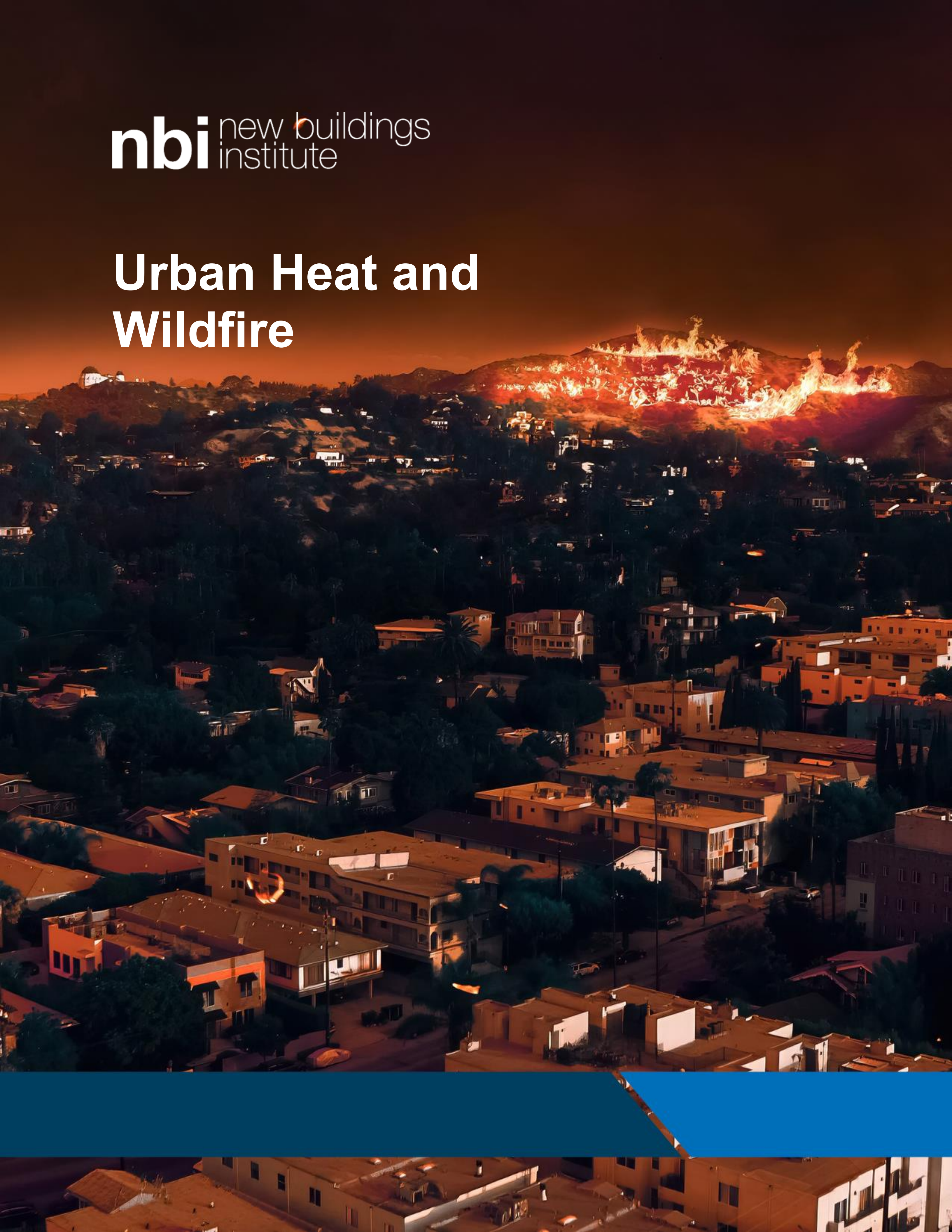


Table of Contents

Urban Heat and Wildfire

Urban Heat

In the US, heat is the most fatal weather event, surpassing floods, hurricanes, and tornadoes, and over four times more fatal than cold temperatures.[1] In cities, heat and its impacts are exacerbated by the Urban Heat Island (UHI) effect, which causes urban areas to be significantly warmer than their surrounding rural landscapes. As buildings and infrastructure replace natural areas, cities lose much of the cooling that nature facilitates, as urban surfaces absorb more of the sun's energy. This raises city temperatures by about 5–9°F compared to surrounding rural areas.[2]

Typical approaches to urban development contribute largely to the UHI effect. Abundant pavements, dense building layouts, and reduced vegetation inhibit cities' abilities to dissipate heat, causing urban materials to absorb and retain solar energy and heat. Darker, low albedo, and impervious surfaces exacerbate this effect by raising temperatures in the air around them. As cooling demand rises in response to increasing temperatures, additional energy consumption adds emissions and further heats the surrounding environment, reinforcing the cycle.

Wildfire

Wildfires in the US have also been increasing in frequency and intensity. Rising temperatures and prolonged drought conditions increase the likelihood of ignition and make the spread of wildfires more difficult to control. Development that sits close to wildland areas in drier climates face increasing risks of fires encroaching on homes, infrastructure, and communities. Wildfires also generate significant amounts of smoke, which spread over long distances, degrading air quality and impacting health.

This Resource

Cities facing a dual risk of extreme heat and wildfire have a unique challenge. Some strategies that are used to mitigate the risk of wildfire—such as building and site hardening—can exacerbate the UHI effect. Other strategies that are used to mitigate heat—like tree shading—can be thoughtfully applied to minimize wildfire risk. Elevated temperatures, in turn, lead to faster wildfire ignition, spread, and increased fire fuel from dense urban layouts.

This resource identifies strategies that policymakers, planners, designers, developers, and others can pursue to reduce the UHI effect while also mitigating wildfire risks and minimizing unintended tradeoffs.

1 National Weather Service
2 Urban Heat Hot Spots: Climate Central

Overview of Strategies

Mitigating both UHI and wildfire requires a comprehensive approach that recognizes how these hazards play out differently across a city. Some strategies that reduce UHI can conflict with wildfire risk reduction priorities, while others—when implemented at scale—can deliver meaningful citywide cooling benefits. Every area of a city has a role to play when it comes to reducing extreme heat.

This resource focuses on the UHI mitigation efforts that are particularly suitable for areas with the highest fire risk. However, a broader set of strategies is appropriate for areas with lower risk, and implementing them remains an important part of a citywide approach.

The table below summarizes five key strategies for mitigating the UHI effect in wildfire-prone cities, organized by the maximum wildfire risk level at which each strategy is appropriate. Approaches for other tiers of risk are also included in the table, though they are not specifically detailed in this resource.

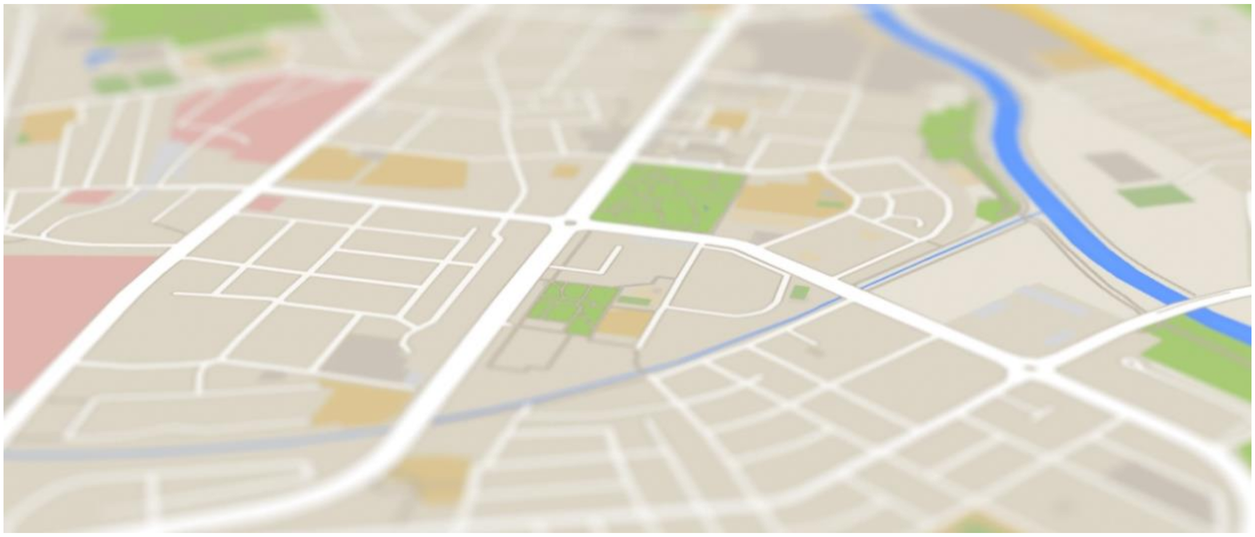
TABLE 1: SUMMARY OF KEY STRATEGIES

Cooling Strategy	Area Fire Risk (Max.)	Wildfire Considerations	Implementation Approaches
Urban Planning and Mapping	**Citywide**	Distinguish levels of risk across the city and implement solutions accordingly.	• Hazard mapping • Zoning and overlays
Streets and Paving	**High**	Light-colored, reflective, porous, and permeable pavements (also known as cool pavements) that are durable can reduce the amount of heat absorbed and are suitable strategies for areas with high fire risk because they do not contribute additional fire fuel.	• Cool pavement and permeable pavement programs • Complete Streets policies
	Medium	Pair cool and permeable pavements with fire-resistant vegetation and use porous or permeable cool pavements.	
	Low	Expand cool roof mandates. Combine cool pavements with dense vegetation and/or tree canopies to maximize cooling corridors.	
Urban Forests and Green Spaces	**High**	Use fire-resistant, drought-tolerant species with moderate spacing to provide shade but prevent fire spread. Use fire resilient species selection, spacing, pruning, and fuel-load management to avoid increasing fire risk. Institute fire-resistant vegetation and fuel-reduction techniques, such as prescribed burns and removal of fire fuels.	• Urban forestry programs • Landscaping requirements and guidelines
	Medium	Use fire-resistant, drought-tolerant species with moderate spacing to provide shade but prevent fire spread. Permit shrubs and groundcovers that stay low to the ground and do not create vertical fire fuel ladders. Integrate green infrastructure features that cool through evapotranspiration but use low-fuel plant palettes.	

Cooling Strategy	Area Fire Risk (Max.)	Wildfire Considerations	Implementation Approaches
	Low	Institute continuous vegetation areas in less fire-prone regions to contribute to citywide cooling. Encourage multi-layered canopy and understory plantings. Expand park cool islands and green corridors. Allow higher-density vegetation, shrubs, and groundcover.	
Site Design	High	Create defensible space with minimum distances based on proximity to building. Trees require minimum spacing from structure and each other. Populate with cool pavements, shade structures, and low-fuel plants. Use noncombustible groundcover or landscaping (landscaping (e.g. stones, gravel, pavers, etc.); and explicitly ban combustible ground cover). Use cool pavement or high-albedo permeable pavements in place of dark asphalt to reduce surface temperatures.	• Zoning and overlays • Landscaping requirements and guidelines
	Medium	Plant trees with minimum spacing. Ground cover permitted but use low-height, low-fueled, and adequately spaced groundcover to avoid transmitting fire to structures. Incorporate non-vegetative, non-combustible shade structures. Use cool pavement or high-albedo permeable pavements in place of dark asphalt to reduce surface temperatures. Cluster vegetation to avoid continuous fuel paths.	
	Low	Allow dense tree canopy and layered vegetation to maximize shade and evapotranspiration. Use continuous vegetated groundcovers to reduce surface temperatures and create cooling corridors. Incorporate shade structures to expand shaded areas. Encourage green infrastructure to cool microclimates. Incorporate shaded walkways, vegetated medians, and pocket plazas. Vegetation adjacent to buildings where fire risk is minimal enables deeper cooling benefits to the building.	
Building Envelope Design	High	Adhere to Wildland Urban Interface (WUI) Code or equivalent. High-albedo building materials for roofs, including walls and facades, reduce heat without vegetation-related fire risk. Use non-combustible shade structures near buildings. Select materials that meet applicable wildfire codes and also have a high solar reflectance and solar reflectance index.[3,4] Limit glazing or provide cool or multi-layered glazing, which can limit heat and effects from wildfire.	• Building code updates • Weatherization programs • Cool roof programs
	Medium	Fire risk for green roofs and green walls depends on plant/species selection, maintenance, and irrigation. Allow green roofs/walls with fire-resistant species and on-combustible substrates. Use high-albedo walls and facades. Incorporate non-combustible exterior shading devices. Encourage passive cooling retrofits.	

[3] Cool Roof Rating Council (CCRC) Rated Roof Directory
[4] Cool Roof Rating Council (CCRC) Rated Wall Directory

Cooling Strategy	Area Fire Risk (Max.)	Wildfire Considerations	Implementation Approaches
	Low	Combine cool roofs, cool walls, and vegetated systems, including green roofs and green walls, for maximum building-level cooling. Promote vegetated shading systems adjacent to buildings. Support passive cooling retrofits including insulation, reflective façades, and operable shading.	



Urban Planning and Mapping

Mitigating both UHI and wildfire hazards requires a comprehensive approach that considers how risk varies across a city. Planning at an urban scale can ensure that the proper mitigation strategies are applied in the proper places, based on localized levels of heat and wildfire risk.

Some strategies to reduce UHI can conflict with wildfire risk reduction priorities. For example, increasing vegetation provides shade and cooling but also introduces fuel that can elevate fire risk.

Planners, urban designers, and the public can play a role in defining and navigating these tensions, helping to maximize the capacity for risk reduction at the city scale.

Mapping Citywide Wildfire and Heat Risk Designations

Different design strategies will be more or less effective in different areas of a city depending on their respective heat and fire risk levels. High-level planning and mapping exercises can help to identify these risks and identify appropriate interventions for particular areas.

Implementation Models

Hazard Mapping

Mapping exercises can inform both wildfire and heat mitigation strategies. Areas located in or around natural spaces often constitute fire-prone communities, particularly along the boundaries where development meets wildland areas—these are typically referred to as the Wildland Urban Interface (WUI).[5] In many states, official wildfire hazard maps are produced for adoption and implementation by municipalities—however, this varies from state to state. Fire resilient development standards are often triggered by WUI designations. Land use planning plays a key role in reducing damage and losses in WUIs. Citywide heat modeling or heat mapping

5 Wildfire and the Wildland Urban Interface (WUI)

campaigns also give jurisdictions a good idea of where the top priority areas should be to pursue cooling interventions.

Understanding both heat and wildfire risks allows planners to determine which strategies are most appropriate in each part of a city. Hotter areas with lower wildfire risk may be best suited for more comprehensive UHI mitigation strategies. In high-risk wildfire areas, planners may instead prioritize lower-risk UHI strategies or focus primarily on wildfire mitigation. High fire risk areas are generally better suited for strategies that emphasize fire resilience over UHI reduction.

Spotlight: California

The state of California identifies Fire Hazard Severity Zones and Responsibility Areas and requires that all of its counties and municipalities adopt General Plans that address these hazards. Fire Hazard Severity Maps are utilized for implementing WUI building standards for new construction.[6] The state has also established a minimum building code and fire safety regulations for buildings located in WUIs.

Spotlight: Los Angeles, California

One US Forest Service-funded program in Los Angeles, California involved a heat campaign conducted in collaboration with community-based organizations. Measurements of air temperature were taken throughout the city; maps generated conversations among public agencies, transportation organizations, workforce development groups, cultural organizations, and others about the areas where future tree planting campaigns could be prioritized. The intent was for these conversations to lead to a series of pilot initiatives showcasing how best to expand and maintain tree canopies within the distinct character of selected neighborhoods, confronting issues such as the strong prevalence of paved area and the costliness of removing it.[7]

City Ordinances, Zoning and Overlays

City and zoning codes serve as a foundational regulatory mechanism for defining and managing land use within specific districts—such as residential, commercial, industrial, market, historic, or financial zones—tailored to local urban context and planning objectives. These codes establish standardized criteria for reviewing development proposals, ensuring consistent implementation of design, safety, and operational standards that support mobility, economic activity, and social cohesion. Integrating provisions for urban heat island (UHI) mitigation, climate resilience, and sustainability measures within these regulations can enhance environmental performance, strengthen adaptive capacity, and promote the long-term social and ecological resilience of the city.

6 California Fire Hazard Severity Zones
7 USDA Forest Service Urban and Community Forestry Program

A legislative body, such as a city council, can enact an ordinance that becomes law, enforceable within the city's boundary. Ordinances can take many forms that guide development and infrastructure interventions, including zoning or building code amendments and the establishment of overlays. For example, an ordinance may require all city-funded projects to incorporate cool surfaces; new public housing to utilize cooling systems; or new construction to be built with fire-resilient building materials.

Zoning codes allow jurisdictions to implement UHI and extreme heat mitigation strategies on a neighborhood or citywide scale. Zoning can impact the density and form of buildings in the city and can be a useful tool for concentrating density to help reduce UHI and move development away from higher-risk WUI zones.

Overlay zones that acknowledge hazard potential may be established in areas particularly prone to environmental risk, including wildfires and extreme heat. Within an overlay zone, regulations may be adjusted to address the particular circumstances of the area. For example, jurisdictions can use zoning and overlays provisions to identify hot spots for introducing green spaces and landscaping; designate buffer zones to prohibit development in areas of high wildfire risk; require a minimum amount of shading on lots; or regulate the quantity or placement of vegetation on private sites. Cities can integrate the WUI Code into their land development code through establishing overlay zones.

Spotlight: Boulder, Colorado

When it comes to promoting density and moderating risk along urban boundaries, some cities have instituted urban growth limits, which can preserve natural land, limit urban heating, and buffer development from wildfire-prone areas. Boulder, Colorado constrained its sprawl by restricting costly extensions of water service to areas beyond certain boundaries. These eventually formed a greenbelt, which has acted as a clear edge between developed land and wildlands as well as a contiguous open space network serving both recreational and conservation purposes. Over the course of several decades, the city managed to establish and maintain a denser urban center by establishing this border through its greenbelt acquisition program, through which it strategically acquired land parcels using a sales tax designated for open-space purchases.[8] In order to implement this plan, voters passed a ballot item to update the city charter. Based on this legal foundation, the city code and Boulder Valley Comprehensive Plan were updated to integrate growth management rules and establish distinctive planning areas based on whether they were already developed or whether they had varying levels of potential and feasibility for annexation. Boulder then purchased open space around the city to prevent future outward expansion.

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8 Sustainable Community Development Code: A Code for the 21st Century

Streets and Paving

By area, streets constitute some of the largest continuous surfaces and public spaces in a city. When designed thoughtfully, they can function as adaptable, multi-purpose environments that meet the diverse needs of the people who use them. Beyond mobility, streets can play a critical role in bolstering a city's resilience to environmental hazards. Cool and permeable pavements reflect solar energy and enhance water evaporation, which contribute to cooling impacts on the cityscape.[9]

The materials and design choices that make up streets directly influence how much they absorb, store, and release heat. Reflective, high-albedo and permeable pavement can significantly reduce surface and air temperatures. Reflective pavements are designed to reduce heat absorption by reflecting solar radiation.[10] Light-colored materials reflect more sunlight and reduce the amount of heat absorbed and reradiated by sun-exposed surfaces. Reflectivity can be achieved by choosing lighter materials, such as concrete or lighter binders and aggregates. Coating or overlaying surfaces with lighter colored materials has also become a common and lower-cost way to prevent heat buildup. Replacing dark surfaces with lighter-colored ones can reduce surface temperatures by up to 20°F during warmer months.[11] White surfaces can reflect between 30 and 80 percent of incoming sunlight back into the atmosphere, compared to fresh asphalt, which reflects only about 4–12 percent.

On high-volume traffic roads, the largest benefit of cool pavements is not due to their UHI mitigation potential, but rather due to their impact on road longevity and vehicle fuel consumption. Permeable surfaces also undergo less thermal expansion compared to impermeable and darker alternatives, leading to longer service lives. Over the lifetime of a pavement, these fuel savings can add up, often offsetting the higher initial cost and impact of paving with more durable materials appropriate for high-traffic roads. Cool pavement

9 EPA: Using Cool Pavements to Reduce Heat Islands
10 Urban Heat: Can White Roofs Help Cool World's Warming Cities?
11 Performance of Cool Pavements for UHI Mitigation

alternatives that minimize fuel consumption can continue to cut GHG emissions in winter, assuming traffic is constant.

Placement of reflective pavements is an important consideration. Recent research has shown that walking on cool pavements can lead to higher temperatures and discomfort for pedestrians, as surface temperature is being reflected. A few studies, for example, found that people standing on reflective pavements on hot, dry days could feel over 7°F hotter compared to standing on uncoated asphalt.[12] This is in large part due to the glare that reflective coatings cause. This issue can be resolved by coating pavements that pedestrians do not directly stand on: treating roadways instead of sidewalks, or treating only shaded sidewalks, can lead to a reduced experience of heating for pedestrians.[13]

In wildfire-prone cities, streets can also serve as buffers and firebreaks. Using noncombustible, light-colored, or permeable materials, managing vegetation, and designing defensible space along the public right-of-way can hinder fire spread and protect buildings and communities.

Available Product Performance

Paving strategies are suitable for areas of all fire risk levels. Hardening efforts in areas with high fire risk can contribute to cooling efforts by selecting light-colored, durable, non-combustible, or permeable materials.[14] Hardscape can be managed with fire-retardant gravels, stone mulch or pavers; vegetation should be minimized in high-risk fire zones to create defensible space.[15]

Cool pavement describes engineered surface treatments with higher solar reflectance that can provide dual benefits by mitigating UHI effects and enhancing fire resistance, helping protect infrastructure and improve public safety. These materials reflect solar radiation in the visible and near-infrared (NIR) spectrum, which can lower pavement surface temperatures by 10–20°F. Many advanced formulations also enhance fire resistance by forming thermally-stable, non-combustible layers that delay ignition and limit flame spread.[16]

Pavements are not typically marked with fire resistance ratings, since they have less risk of being combustible. Therefore, paving materials and coatings are not typically marketed with Class A, B, or C fire ratings.

Alternative Asphalt Mixes (Reflective Aggregates and Polymer-Modified Binders)

The typical dark color of asphalt tends to absorb solar radiation, contributing to the UHI effect. Conventional asphalt pavements typically contain about 90–95 percent mineral aggregates and 5–10 percent bituminous binder by weight. This makes the surface difficult to ignite but can still be combustible under intense fire exposure. Asphalt can also lose structural integrity under high heat, even without wildfire. Modifications can be made to asphalt mixes to enable them to

12 The Hottest Urban Heat Solution Comes with a Glaring Tradeoff
13 UNEP: Beating the Heat: A Sustainable Cooling Handbook for Cities
14 Evaluating Performance of Cool Roof Pavements for UHI Mitigation
15 Fire Smart Landscape Basics
16 Research on Flame Retardancy Properties for Modified Asphalt

withstand both heat and wildfire conditions. Lighter-colored asphalt mixes or reflective surface coatings can be incorporated to increase albedo and reduce the impact on UHI. Flame-retardant modifiers such as aluminum trihydrate, magnesium hydroxide, expanded graphite, or similar materials may also be added binders to build fire resistance by delaying ignition, lowering peak heat-release rate, and reducing smoke and toxic emissions. Polymer-modified asphalt, polymer-based binders, and nano-additives like nano-clay or nano-silica can also raise the softening point of the mixture and improve high-temperature stability, helping pavements better withstand extreme heat; some surface coatings can also act as sacrificial protective layers against ember attack as well as thermal degradation.[17,18,19]

Concrete Alternatives

Portland cement concrete is noncombustible and more resistant to direct flame and high temperatures than asphalt, meaning that concrete pavements tend to maintain structural integrity longer during wildfires. Using light-colored concrete or applying reflective coatings such as suitable epoxy or acrylic systems, can further increase albedo and help mitigate urban heat island effects around roadways and hardscapes. Thus, it is wise to apply concrete where fire severity and access needs are greatest, such as bridge decks, critical intersections, and WUI evacuation routes.[20,21]

Permeable Blocks, Pavers, and Grid Systems

Because pavers are individual units, they are durable as well as easy to maintain, repair, and replace, which can reduce long-term operational impacts. Pavers designed as a closed-grid system are not permeable, and pavers designed as an open-grid system are permeable. Open-grid systems allow gaps to be filled with gravel or vegetation or remain free of joint fill material for maximum infiltration capacity. Pavers are commonly manufactured from concrete, fired-clay brick, natural stone, or other durable materials. Light-colored concrete or stone pavers are preferred for heightened UHI and wildfire resilience. These materials are non-combustible, help reduce surface heat buildup, and can better withstand radiant heat and ember exposure during wildfire events. Near buildings, non-combustible hardscape materials—such as concrete, fired-clay brick, or natural stone—paired with non-combustible gravel or stone mulch—rather than plastic or vegetated grid systems—will lower fire risk.[22] Strategic planting can still be incorporated where fire risk is lower, provided vegetation is well-maintained and does not create continuous fuel pathways.

Pollution Redoxing Agents

Pollution-reducing, photocatalytic pavement treatments use semiconductors like titanium dioxide (TiO_2), applied as a spray or coating on asphalt or concrete. Under sunlight, TiO_2 oxidizes pollutants such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs), which

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17 Polymer-Based Flame-Retardant Asphalt: A Comprehensive Review of Materials, Performance, and Evaluation Methods
18 Evaluating Road Resilience to Wildfires: Case Studies of Camp and Carr Fires
19 Pavement Resilience: State of The Practice
20 Evaluation of concrete pavers affected by Manavgat wildfires
21 Microstructure of fire-damaged concrete. A case study
22 Climate Resilience Toolkit

improves local air quality. These treatments can also increase surface reflectivity, which can reduce pavement temperatures. By rejuvenating the binder and slowing oxidation, they can extend pavement service life and reduce maintenance-related emissions.[23,24]

High Solar Reflectance Coatings

High solar reflectance coatings can be applied to asphalt or concrete to increase albedo and reduce their heat gain without altering the underlying pavement structure. These products include light-colored acrylic coatings that add reflectivity and resist discoloration under high temperatures. Transparent epoxy coatings can provide chemical, skid, and solvent resistance.[25,26] One peer-reviewed study from the Altostratus Cool Community Project in the Pacoima neighborhood of Los Angeles, California found that application of solar reflective coatings on pavement reduced ambient air temperature by up to 3.5°F during extreme heat events, resulting in a 25–50 percent reduction in local UHI intensity during peak temperatures.[27]

Heat-Reflective Coatings

Heat-reflective coatings reflect solar radiation across UV, visible, and infrared wavelengths and can reduce asphalt surface temperatures by up to 10–20°F, depending on climate and product type.[28] Photocatalytic TiO_2-based coatings are reflective, self-cleaning surfaces, which can degrade total volatile organic compounds (TVOCs) while maintaining surface brightness for UHI mitigation.[29] IR-reflective (NIR/IR) coatings contain pigments that reflect near-infrared and mid-infrared wavelengths, enabling up to 18–22°F surface cooling, even under intense heat exposure.[30]

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23 Sinak Sustainable Building Solutions
24 Raleigh curbs urban heat islands through pavement rejuvenation
25 Epoxy Coating
26 Materials to Mitigate the Urban Heat Island Effect for Cool Pavement: A Brief Review
27 Peer-reviewed Study on GAF and Climate Resolve Initiative Demonstrates Effectiveness of Cool Pavement Coatings in Mitigating Extreme
28 Comparison and analysis on heat reflective coating for asphalt pavement based on cooling effect and anti-skid performance
29 Evaluation of photocatalytic efficiency of TiO_2 applied over cement plaster for mitigating urban air pollutant: TVOC
30 Evaluating the performance of cool pavements for urban heat island mitigation under realistic conditions: A systematic review and meta-analysis

TABLE 2: SUMMARY OF AVAILABLE PAVING PRODUCTS AND THEIR UHI AND WILDFIRE PERFORMANCE

Product Type	UHI Performance	Wildfire Performance
Alternative Asphalt Mixes and Binder Modifications	• Reflective coatings can reduce surface temperatures by up to 20°F. • Cooling effect can improve performance of asphalt mixtures in the field.	• Difficult to ignite but still combustible under intense fire exposure. • Flame-retardant modifiers added to the binder can delay ignition, lower peak heat-release rate, and reduce smoke and toxic emissions.
Concrete Additives	• Some additives (vermiculite, perlite, crushed glass) reduce thermal conductivity and daily temperature swings. • Reduces heat retention.	• Portland cement concrete is non-combustible and more resistant than asphalt to direct flame and high temperatures.
Permeable Articulating Concrete Blocks	• High solar reflectance can mitigate UHI impacts when compared to conventional asphalt pavement. • Evaporative cooling when wet can mitigate UHI.	• Non-combustible hardscape materials are fire resilient.
Permeable Interlocking Concrete or Brick Pavers	• Provide permeability. • Light-colored pavers can increase reflectivity. • Infiltration reduces surface heat.	• Non-combustible hardscape materials are fire resilient.
Grass Pavers	• Absorb less heat than conventional paving like asphalt and concrete. • Evapotranspiration cools surfaces. • Must be maintained and irrigated.	• Vegetation is more flammable than non-combustible hard materials, but strategic planting can improve resilience.
Gravel-Filled Concrete Grid System	• Gravel surfaces store less heat than asphalt. • Lacks reflectivity. • Open-grid structure reduces heat retention.	• Strategic planting and non-combustible gravel or stone mulch near structures instead of plastic or vegetative grid systems can improve resilience.
High-Solar Reflectance and Heat-Reflective Coatings	• Reflects solar radiation through high-albedo surfaces and reduces heat gain without structural or material modification. • Some reflect solar radiation across UV, visible, and IR wavelengths. • Successful at reducing ambient air temperature. • Some constitute flexible films that expand and contract with temperature changes, reducing cracking.	• Some varieties can expand and contract with temperature changes, reducing cracking and maintaining durability in high-heat or wildfire-prone environments. However, some varieties can crack, leaving the surface vulnerable to wildfire. • Some varieties are able to maintain durability in high heat or wildfire. • Non-flammable coatings can prevent flame spread.
Pollution Redoxing Agents	• Reflective, self-cleaning surfaces that can degrade total volatile organic compounds (TVOCs) while maintaining surface brightness for UHI mitigation. • Can slightly reduce temperatures, but not the primary function.	• No studies on wildfire performance.

Implementation Models

Cool Pavement Programs

Cool pavement programs are municipal initiatives that can be designed to implement, test, monitor, and scale pavement treatments and technologies that stay cooler than conventional paving. These are often instituted on municipally owned streets, alleys, parking lots, and schoolyards. Some programs incorporate pilot testing phases that install multiple pavement types, measure relative performance, and document findings for future use. These findings can be used to expand the most promising installations where the benefits can be felt the most.

Spotlight: Pacoima, California

In summer 2022, more than 700,000 square feet of dark asphalt in the Pacoima neighborhood of Los Angeles were coated with a solar-reflective pavement treatment, through a partnership between Climate Resolve, GAF, StreetBond, StreetsLA, and local community groups.[31] The project paired cool pavement applications with other beautification and resilience initiatives such as solar-reflective murals, cool roofs, and park improvements. The coatings applied also lowered surface temperatures by up to around 10°F. During extreme heat events, the cool pavement-covered area realized ambient air temperatures that were around 3.5°F cooler than those in adjacent areas. On sunny days, ambient air temperatures were reduced by up to 2.1°F.

Complete Streets Policies

The "complete streets" concept emphasizes a move away from car-centric street designs to those that equally prioritize the needs, convenience, comfort, and safety of all users of varying physical capabilities, including pedestrians and cyclists as well as drivers and riders of public transit. Typically, complete streets incorporate clearly marked bicycle lanes with separation from vehicular traffic; sidewalks that are wide, well-maintained, and adequately lit; bicycle lanes; ample and visible crosswalks; and transit stops with sheltered seating for riders to wait comfortably. Many complete streets also include traffic calming measures to protect pedestrians. These policies provide opportunities to incorporate cooler materials. Incorporating green elements helps mitigate the impacts of extreme heat: removing heat-absorbing pavement and planting vegetation in its place can cool and shade urban neighborhoods and mitigate smog during hotter months. In fire-prone areas, these green pathways can incorporate fire-resilient species with mindful spacing.

31 Pacoima Pavement Experiment

Spotlight: Phoenix, Arizona

In 2017, the City of Phoenix, Arizona passed a complete streets policy in acknowledgement of residents' emerging interest in incorporating other transportation modes into their routines. The policy emerged in part as a response to a growing concern over dangerous walking conditions that often resulted in pedestrian fatalities; in 2016, Arizona had the highest rate of pedestrian deaths in the country.[32] The policy calls for all new and retrofitted streets to consider all modes and uses for a public right-of-way. The city also adopted a Complete Streets Design Guide, which describes how to improve streets in different contexts, ranging from low-density suburban contexts to high-density urban areas as well as industrial and mixed-use ones. The guidelines draw from the National Association of City Transportation Officials' Urban Street Design Guidelines.

Across the city, complete streets have been introduced incrementally through new developments and retrofits. Central Avenue, a major north-south thoroughfare in downtown Phoenix, now includes a dedicated light rail line, bike lanes, and wide sidewalks with ample shade from street trees. Roosevelt Row, which runs through the downtown revitalized arts district, also includes bike lanes, street trees, widened sidewalks, and public art installations. 7th Street and Indian School Road, other major arterials, include bike lanes, widened sidewalks, enhanced pedestrian crossings, a new bus rapid transit line, and native and drought-tolerant landscaping to provide shade.

The city also instituted a Cool Pavement Program, which utilized a relatively quick and low-cost method to cool down street surfaces by coating streets with light, reflective paint. This coating has proven to reduce street temperatures by 10–12°F and helped to sustain the quality of street surfaces by reducing the number of potholes.

[32] Pedestrian Deaths in Phoenix

Urban Forests and Green Spaces

In the US, an average of 40 percent of urban areas is covered by trees, but that number is declining; impervious surfaces, meanwhile, are expanding. In many cities, the geographic divide between areas with and without tree cover mirrors demographic lines, namely race and income, contributing to hotter conditions in historically disinvested neighborhoods.[33, 34]

City trees and greening help regulate a city's microclimate and alleviate the UHI effect by providing shade and cooling from evapotranspiration, and reducing the heat absorbed by manmade surfaces and buildings. In fact, urban surfaces shaded by trees can be up to 20–45°F cooler than unshaded ones in the summer.[35,36] By capturing carbon and storing it in their biomass, trees also help to control urban greenhouse gas emissions; in the U.S., urban forests offset climate pollution equivalent to the emissions of about 10 million cars.

Introducing new vegetation and preserving existing green spaces throughout a city can offer a range of other benefits, in addition to reducing summer temperatures. These include increased biodiversity; carbon sequestration; reduced pollution; decreased winter wind speeds; absorption of stormwater; and positive effects on human health.

Cultivating natural spaces can be useful for buffering development from wildfire, helping to sustain community survivability.[37] During the 2019 Kincade Fire in California's Bay Area, for example, greenbelt areas helped to contain the wildfire and reduced the impact on nearby neighborhoods.[38] However, open spaces can also pose risks in arid areas: fire-prone communities must take extra care along the boundaries of development, where built area meets nature. Typically referred to as the wildland urban interface (WUI), these zones face heightened risks from wildfires that are

33 Tree Equity
34 Residential Housing Segregation and Urban Tree Canopy in 37 US Cities
35 The little-known physical and mental health benefits of urban trees
36 EPA: Using Trees and Vegetation to Reduce Heat Islands
37 Wildfire and the Wildland Urban Interface (WUI)
38 Heeding the Power of Nature to Build Wildfire Resilience

typically fueled by larger swaths of vegetation. If not designed and maintained thoughtfully, urban forests and green spaces also hold the potential to increase wildfire risk. Trees, shrubs, grasses, and accumulated vegetation serve as combustible material in hot, dry conditions, which can ignite more easily and promote fire spread. Dense, continuous vegetation are primary facilitators of a fire's ability to move more freely, particularly in drought-stressed or dry areas. When vegetation is placed proximate to development, this can pose a risk to buildings and infrastructure. Urban forests located adjacent to WUI zones can also increase ember exposure and facilitate continuous fuel spread from wildlands into developed areas.

Preparation and maintenance can mitigate the impact of wildfires in urban parks, forests, and green spaces. For example, placement and configuration of these spaces—including the incorporation of firebreaks to slow down spread—can go a long way in minimizing fire risk. Additionally, incorporating fire-proof vegetation, native plants (which tend to be wildfire resistant) and removing fire fuel from parks also helps to inhibit wildfire from spreading into protected areas.

Placement and Configuration

Vegetation can be introduced along transportation routes, on public lands, or on private lands. Urban pockets of vegetation, including parks, have the capacity to generate urban cooling islands: areas of a city that are significantly cooler than their surrounding built-up areas. Landscaped vegetated areas do not need to be particularly large to generate this effect: one study observed that a vegetated island spanning around 200 feet could generate a cooling effect within a 330-foot radius; this phenomenon can grow exponentially as the vegetated space gets larger.[39]

In wildfire prone areas, vegetation should be arranged to break up fuel continuity—for example, in separated clusters with maintained gaps. This minimizes the risk of fire spreading through vegetated pathways. Parks, greenways, and landscaped corridors can function as buffers when designed with noncombustible hardscape edges, irrigated low growing vegetation, and well-spaced trees with pruned canopies. The International WUI Code prescribes a minimum of 10 feet of space between the crowns of trees in defensible spaces. In the WUI, creating a gradient, with buffers, between development and more lush, vegetated areas minimizes fire exposure to development while also retaining the cooling benefits of green spaces.

Species Selection

Pairing fire-resistant species with proper spacing, irrigation, and routine maintenance ensures that vegetation can contribute to cooling without increasing wildfire exposure.

Species selection is therefore key for reducing landscape flammability and improving resilience in fire-prone areas. Certain traits are often strong indicators of a plant's level of flammability—these include moisture content, resin or oil concentrations, or leaf composition.[40] Plants with high leaf moisture content, low resin or oil concentrations, and broad, fleshy, or thick leaves tend to have lower ignition levels and burn more slowly. Species that have limited litter

[39] Vegetation as a climatic component in urban street design
[40] Status and Prospects of Plant Flammability Measurements

accumulation also reduce the likelihood of flame spread. Conversely, plants with dry foliage, peeling bark, or dense, compact forms can act as fuels or produce embers. Drought tolerant plants that have evolved to maintain hydration during prolonged heat or water stress are also less likely to contribute to fire spread. Tree species that have higher canopies, shrubs that stay low and open, and groundcovers that do not accumulate dry thatch can be combined to minimize fire spread. Selecting plants with manageable debris and irrigation needs supports long-term resilience and reduces maintenance burdens.

Native species are often advantageous because they are adapted to local moisture regimes, soils, and climate variability, which helps them maintain healthier, less stressed foliage during drought and extreme heat—conditions that otherwise increase plant flammability. Many native species also have structural traits that reduce ignition potential, such as higher leaf moisture content, low resin or oil levels, thicker bark, and growth forms that limit the accumulation of fine, dry fuels. When selecting species near buildings or within the WUI, prioritize plants with low flammability ratings, avoid species with fine or resinous foliage, and choose trees that naturally maintain higher canopies to reduce ladder fuels.

A growing number of guidelines have emerged to provide criteria for selecting and arranging vegetation to reduce wildfire risk in the WUI. The International Wildland Urban Interface Code (IWUIC) Appendix F, for example, focuses on characteristics of fire-resistive vegetation.[41] The Insurance Institute for Business & Home Safety (IBHS) also published a Wildfire Prepared Home standard for single- and multi-family homes.[42] LEED's SITES framework also includes a credit for reducing the risk of wildfire, including a firewise landscaping checklist.[43] State and regional agencies also publish plant selection lists and landscape design guidance tailored to local ecosystems. For example, Cal Fire's "Fire-Smart Landscaping" guidelines, the University of California's Fire-Resistant Landscaping recommendations, the Colorado State Forest Service's Fire-Wise Plant Materials list, and the Oregon State University Fire-Resistant Plants guide provide guidance on landscape placement and fire-safe plant selections.

Pruning and Fuel-Load Management

Effective pruning and fuel load management are essential for reducing wildfire risk in landscaped spaces. Regular pruning removes dead or dying branches, raises tree canopies to reduce ladder fuels, and maintains adequate spacing between tree crowns so that fire cannot easily move from tree to tree. Managing ground fuels—such as leaf litter, dry grasses, woody debris, and accumulated duff—similarly reduces the likelihood of fire spread and increased intensity. Routine removal of dead vegetation, thinning of overly dense shrubs, and maintenance of irrigated, low-growing groundcovers can therefore significantly lower risk of ignition and spread.

[41] International Wildland Urban Interface Code Appendix F
[42] IBHS Wildfire Prepared Home Standard
[43] LEED SITES Rating System

Implementation Models

Urban Forestry Programs

Urban forestry programs are municipally-, regionally-, or, in some cases, state-administered initiatives that plan, plant, maintain, and expand tree canopy cover across urban and suburban areas. Programs typically include street tree inventory and canopy assessment; equity-focused planting targets prioritizing heat-vulnerable neighborhoods; species selection protocols counting for specific local conditions including drought and wildfire; and ongoing maintenance including pruning and fuel-load management, soil management, and tree health monitoring. Street tree programs are also common mechanisms, administered by public works or urban forestry divisions, which maintain approved species lists, planting specifications, and right-of-way standards governing trees in the public realm. In fire-prone areas, urban forestry programs are fitting for designating and maintaining defensible space principles and fire-conscious species selection.

Spotlight: California

California's State Urban Forestry Program offers grants while working with CAL Fire's Fire Prevention Program in advocating fire-safe landscaping.[44] It encourages compliance with defensible space requirements for communities in the WUI, offering suggestions for tree types, landscape designs, and pruning methods. This offers an effective model for integrating urban canopy grants with fire impact considerations.

Landscaping Requirements and Guidelines

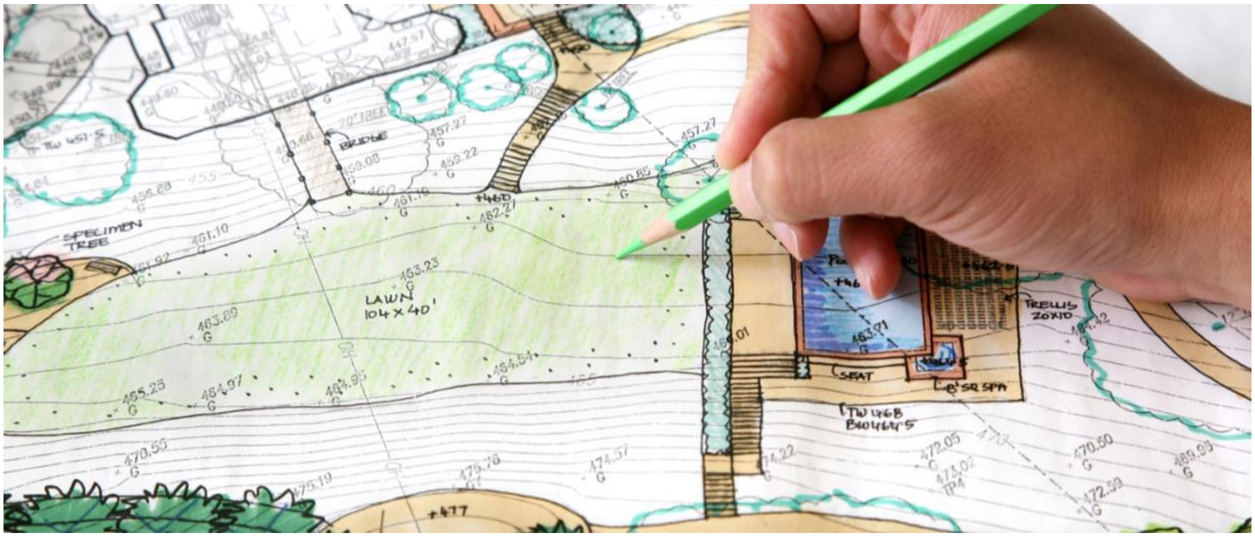
Municipal landscaping requirements and guidelines operate through a range of regulatory mechanisms, but often through zoning or development codes, which establish baseline landscaping standards as conditions of development approval. This may constitute specifying minimum canopy coverage percentages, parking lot tree ratios, street tree planting requirements, or other provisions. Similar to street tree programs, these regulations may reference approved species lists or planting specifications, but would apply to private development. These specifications and guidelines typically constitute landscaping types that have been pre-vetted by a municipality for use on public or private development.

[44] California Urban and Community Forestry Grants

Spotlight: Boulder, Colorado

Boulder, Colorado has taken an integrated approach to addressing landscaping risks, having produced a Guide to Wildfire Resilient Landscapes. The city offers guidance on managing urban landscapes in the WUI with a focus on reducing wildfire risk; increasing water use efficiency; managing extreme heat; and enhancing environmental health and biodiversity. The guide includes comprehensive landscaping guidance and best practices for planting within a building's buffer area, landscaping maintenance and selection, mulching and planting, case studies, and recommended regulatory requirements. The city also has an Urban Forestry program that explicitly cross-references WUI fire risk areas. It maintains an approved tree and plant list for these zones, along with guidance on species selection, pruning heights, and spacing.[45]

[45] Boulder Wildfire Resilient Landscapes



Site Design

Site design deals with decisions regarding building placement, shading, vegetation, and landscape design. Consideration at this scale is important because each development contributes incrementally to regional heat and wildfire vulnerability. Poor choices at the site scale can undermine broader resilience efforts and also have unintended consequences felt by neighboring developments.

Wildfire mitigation strategies can often be in tension with UHI reduction strategies in this context. For example, trees and dense plantings can reduce UHI through shading and evapotranspiration but certain species can increase fuel and fire spread risk. Irrigated landscapes and green infrastructure also help mitigate UHI and keep sites cool, but maintaining irrigated vegetation in drought-prone, fire-risk regions may not be sustainable or will contribute to water shortages.

International Wildland Urban Interface (WUI) Code Provisions

The International Wildland Urban Interface (WUI) Code is a model code available for jurisdictions to adopt to strengthen fire-resilient building requirements in higher-risk areas. Nearly 200 jurisdictions in the US have adopted this code. In 2020, for example, the city of Austin, Texas adopted the code after identifying the high risk posed by a large portion of its structures. The code now applies to new construction and renovations located near fire-prone vegetation, between the urban center and wildlands, a total area constituting around two-thirds of the city. Ultimately, buildings and sites complying with the WUI Code have proven to be effective in reducing damage from wildfires. After the Camp Fire in Paradise, California, over half of the homes that had been built after the state adopted a WUI-specific fire-safe building code were able to evade damage; by contrast, only 18 percent built before the code was adopted were safe.[46]

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[46] WUI: Three Letters at the Core of Wildfire, Housing, and Land Use

The WUI Code addresses elements pertaining to site layout and design, addressing how a site should be arranged, cleared, accessed, and maintained. Some of these provisions are summarized below, from the lens of their interaction with UHI impacts.

TABLE 3: KEY WUI CODE PARAMETERS ON SITE DESIGN AND UHI CONSIDERATIONS

Fire-Resilient Parameter	UHI Performance and Considerations
Defensible Space (0–30 ft) and Structure Separation/Spacing (WUI Code Sections 503.1, 603, 604) **Access Roads and Driveways** (WUI Code Sections 402.1, 402.2, 403.2)	• More hardscape can worsen UHI. Removing vegetation reduces natural cooling. • Populate relevant areas with cool pavements, shade structures, low-fuel plants to mitigate impact on UHI. • See "Streets and Paving" section of this resource for material selection.
Fire-resistant Landscaping and Spacing (WUI Code Sections 603, 604)	• Low-fuel plants can provide cooling, but a widely spaced tree and shrub canopy as required can reduce shade. • Ground cover is permitted in defensible space and can reduce UHI. • Trees are permitted in defensible space but must be spaced 10' apart and away from structure. • Characteristics of fire-resistive vegetation provided in Appendix F.
Shading Devices Built With 1-Hour Fire-Resistance Rated Construction (WUI Code Section 504.7)	• Adjustable devices can deflect direct sunlight at certain times of the day while still allowing light or heat to enter when desired. • Adjustable devices can also be moved or removed during a wildfire event.

Defensible Space, Structure Separation, and Access

The WUI Code designates the area directly surrounding a building as the defensible space, an area where natural vegetation is thinned, reduced, or removed to limit fire spread. Possible pathways for fuel spread are broken up to lower flame lengths and reduce radiant heat so a structure is less likely to ignite. The distance of the defensible space varies depending on the level of fire hazard on the site, ranging from 30 feet for moderate hazard to 100 feet for extreme hazard. At minimum, it is best practice to situate a 5-foot non-combustible hardscape surrounding a building.[47] In addition to provisions for defensible spaces, the WUI Code contains requirements for roadway access and driveway design to facilitate seamless emergency response that can reach structures during a wildfire.

Both of these strategies require some level of hardscape and paving: these can be designed to mitigate heat impacts by integrating cool pavements or supplying shade structures. Additionally, with thoughtful design, defensible spaces need not necessarily constitute barren hardscapes: the WUI code does allow for vegetation in these zones, though it must be maintained so that tree crowns remain separated by at least 10 feet, deadwood is removed, and other groundcover is spread out enough to not facilitate fire spread.

[47] City of Boulder Wildfire Ready Plant & Vegetation Guide

Shading Devices

Adjustable shading elements can deflect direct sunlight at certain times of the day while still allowing light or heat to enter when desired. These elements may be integrated into a building's design or added after the fact. They may constitute roof overhangs, shutters, porches, curtains, or canvas canopies—a more efficient, cheap, and easier option to apply. However, in high fire hazard areas, combustible shading elements should be avoided. Shading is typically needed most on the western and eastern elevations, which receive the most direct sunlight during the summer.

Fire-Resistant Landscaping

Species selection also applies at the site level. See the Urban Forests and Green Spaces section for more information on this topic.

Implementation Models

Zoning Codes and Overlays

As described earlier in this resource, zoning codes allow jurisdictions to implement UHI and extreme heat mitigation strategies on a neighborhood or citywide scale. Zoning can impact density and form of buildings in the city, and can be a useful tool for concentrating density to help reduce UHI and move development away from higher-risk WUI zones. Zoning codes can also define site design parameters such as landscaping, setbacks, and other building form requirements. Overlay zones that acknowledge hazard potential may be established in areas particularly prone to environmental risk, including wildfires and extreme heat. Within an overlay zone, regulations may be adjusted to address the particular circumstances of the area. For example, jurisdictions can use zoning and overlays provisions to identify hot spots for introducing green spaces and landscaping; designate buffer zones to prohibit development in areas of high wildfire risk; require a minimum amount of shading on lots; or regulate the quantity or placement of vegetation on private sites.

Spotlight: Santa Fe, New Mexico

Santa Fe has integrated the WUI Code into its land development code. Additionally, in 1992, the city of Santa Fe established a 500-acre “Escarpment Overlay District,” focused on reducing the area’s burn risk.[48] Through ordinance, the city prescribed specific guidelines for building in this area, including the reduction of required vegetative density in higher fire risk areas.[49] The city has employed an integrated approach within this overlay zone, balancing considerations for wildfire reduction with preserving the natural landscape, long-term growth management, and economic development.

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48 New Mexico: Climate Resilient Development at the Local Level
49 New Mexico: Community Planning Assistance for Wildfire

Landscaping Requirements and Guidelines

Municipal landscaping requirements and guidelines operate through a range of regulatory mechanisms, but often through zoning or development codes, which establish baseline landscaping standards as conditions of development approval. This may constitute specifying minimum canopy coverage percentages, parking lot tree ratios, street tree planting requirements, or other provisions. Similar to street tree programs, these regulations may reference approved species lists or planting specifications, but would apply to private development. These specifications and guidelines typically constitute landscaping types that have been pre-vetted by a municipality for use on public or private development.

Spotlight: Boulder, Colorado

Boulder, Colorado has taken an integrated approach to addressing landscaping risks, having produced a Guide to Wildfire Resilient Landscapes. The city offers guidance on managing urban landscapes in the WUI with a focus on reducing wildfire risk; increasing water use efficiency; managing extreme heat; and enhancing environmental health and biodiversity. The guide includes comprehensive landscaping guidance and best practices for planting within a building's buffer area, landscaping maintenance and selection, mulching and planting, case studies, and recommended regulatory requirements. The city also has an Urban Forestry program that explicitly cross-references WUI fire risk areas. It maintains an approved tree and plant list for these zones, along with guidance on species selection, pruning heights, and spacing.[50]

[50] Boulder Wildfire Resilient Landscapes

Building Envelope Design

Balancing building scale strategies for both urban heat island (UHI) mitigation and wildfire resilience presents a unique set of challenges. Buildings are large culprits when it comes to contributing to urban heat. They also present a significant vulnerability during wildfire events, as they can cultivate ignition and spread of embers and flame. Buildings are a significant line of defense from harm during extreme weather events: envelopes are therefore a critical barrier for protecting human health and safety during extreme heat and wildfire events. UHI and wildfire requirements often converge at the building scale, making buildings a critical point for reconciling any conflicting demands or requirements. Replicating thoughtful envelope strategies from structure to structure means that decisions made at the building scale can have cumulative impacts across a city.

International Wildland Urban Interface (WUI) Code Provisions

The WUI Code addresses elements pertaining to building envelope performance and design. Some of these provisions are summarized below, with guidance on how to integrate heat mitigation into these activities.

TABLE 4: KEY WUI CODE PARAMETERS ON BUILDING DESIGN AND UHI CONSIDERATIONS

WUI Code Parameter	UHI Performance and Considerations
Ignition-Resistant and Noncombustible Exterior Materials (Sections 503.2, 504.5)	• Light-colored, high-reflectance, or high-albedo, non-combustible materials reduce heat absorption and do not add fire risk. • Less-reflective materials can increase heat. To avoid, specify high-albedo cladding.
Class A Roof Coverings (Highest Fire Resistance) (Section 504.2)	• Cool roof materials often meet Class A requirements (the highest fire-resistance rating available), but not all cool roof materials will always meet wildfire performance standards if they are combustible or prone to ember intrusion. Some fire-rated shingles have low reflectance. • Specify a high solar reflectance requirement for each roof material type that meets Class A requirements (this is described in further detail in the section on Cool Roof and Wall Material Selection).
Tempered, Multilayered Glazing (Section 504.8)	• Better insulation can reduce cooling loads. • Pair with noncombustible shading devices if glazing is anticipated to increase solar heat gain.
Noncombustible Decks and Projections (Section 504.7)	• Light-colored ignition-resistant decking can reduce heat. • Metal or concrete decking or pavers can be specified with high reflectance.
Protected Eaves, Soffits, Fascia (Section 504.3)	• Insulated assemblies can reduce heat gain. • Conflict: Cross-ventilation strategies improve thermal comfort and can relieve heat in drier climates but can also allow smoke or embers to enter.

Air Sealing and Weatherization

The building envelope plays an important role in establishing a building's thermal resilience as well as indoor air quality protection during extreme heat and wildfire smoke events. High-performing envelope systems can reduce interior heat gain by insulating against outdoor temperature swings and can prevent smoke and air pollutant infiltration from entering into indoor spaces during wildfire events.

Air leakage is a large culprit for indoor heat gain as well as the accumulation of particulates resulting from wildfire smoke.[51] When the building envelope has gaps, cracks, or poorly sealed joints, hot outdoor air infiltrates the interior, increasing indoor temperatures and forcing cooling systems to run longer and at a higher capacity to maintain indoor temperatures.[52] Weaker envelopes make mechanical equipment, including those used for cooling, less efficient, increasing energy use and associated costs to cool a space. During smoke events, particulates entering through leaky envelopes can also bypass filtration in the mechanical systems.

Well-sealed envelopes improve both thermal performance and indoor air quality, enabling mechanical cooling and filtration systems to operate as designed and maintain safe indoor conditions during extreme heat and smoke events. Air sealing and weatherization upgrades are impactful ways to strengthen envelope integrity, helping with thermal resilience to extreme heat while protecting from bad air quality during wildfires. Key weatherization strategies with dual benefits for heat and smoke include rooftop and wall insulation to reduce heat transfer and stabilize indoor temperatures; air sealing of the exterior envelope to block smoke and reduce infiltration; introducing high-performance fenestration (double-glazed, low-E, well-sealed windows); incorporating exterior shading devices such as overhangs, louvers, or screens with fire resistant materials; designing cool or green roofs to reduce roof surface temperatures and cooling loads; and using mechanical ventilation with filtration (MERV 13 or higher) for smoke events.[53] These strategies may be applied to both new and existing buildings.

Ventilation

While the WUI Code requires a tightly sealed exterior envelope to prevent embers and smoke from entering attic and interior spaces, this can conflict with some passive cooling strategies, especially in hot, dry climates where cross-ventilation can flush out heat from interior spaces. Cross-ventilation strategies often require large, operable openings on opposing facades, which can be opened at night and during stretches of cooler temperatures to flush out indoor heat gained over time.[54] However, the fire-conscious provisions urge against integration of unscreened vents, open eave soffits, and other wall openings. This can be reconciled by designing two different modes: a sealed mode for wildfire events and an operable mode for heat events. Controllable, ember-safe openings, for example, can be opened or closed depending on

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51 NIST: Wildfire Smoke Impacts on Residential Indoor Air Quality
52 US Department of Energy: Air Leakage
53 ASHRAE, EPA, NIST: Planning Framework for Protecting Commercial Building Occupants from Smoke During Wildfire Events
54 EPA: Extreme Heat and Indoor Air Quality

air quality conditions. These might include baffled, ember-resistant vents, operable windows tied to air quality or smoke sensors, or night-flush ventilation systems that can be disabled during wildfire events. These allow buildings to maintain protection during fire events while still supporting natural cooling when it is safe to do so.

These tensions also exist at the mechanical level. HVAC systems facilitate ventilation by exchanging indoor and outdoor air or recirculation and cleaning indoor air. The exchange of indoor and outdoor heat is not always optimal for extreme heat conditions, under which intake of outdoor air should be minimized and rejected heat exhausted to the exterior of the building worsen outdoor air temperatures and contribute to the UHI effect. Recirculation of indoor air also comes with complications during wildfire events. Reduced ventilation and minimization of outdoor air is effective for short periods to preserve health and safety during poor air quality events. However, reducing intake air too much or for too long can create negative building pressure that fosters intake of bad air through leaks in the envelope.[55] To manage these, mechanical ventilation strategies can be balanced to combine controlled outdoor air intake with high-efficiency filtration. Pressuring the building with positive air pressure and utilizing dampers and economizers can keep wildfire smoke from seeping indoors. Smart or sensor-driven HVAC controls also exist to automatically adjust outdoor air intake based on temperature, particulate levels, and pressure.[56] Finally, if an HVAC system is not designed to reduce particulate concentrations sufficiently, portable air cleaners, with HEPA filters, may be utilized.

Façade, Wall, and Window Design

In addition to promoting air sealing and weatherization strategies, material choices for walls can offer dual benefits for heat and fire. Materials with high thermal mass have the potential to store thermal energy and shield interior spaces from external temperatures during the day. Placing heavier, denser materials such as concrete, stone, or masonry strategically throughout the structure, including as flooring and for interior walls, absorbs heat from the sun during the hottest hours and distributes it slowly as outdoor temperatures drop during the evening and night. For this reason, thermal mass is best employed in hot and dry climates, where nights are cooler. Many materials with thermal mass benefits also offer higher fire resilience qualities as many are non-combustible.

For lighter weight claddings, selecting materials with a high-albedo can help reduce cooling loads in warmer climates. Cool walls and siding can provide similar UHI benefits to roofs when specified with non-combustible, high-reflectance materials.

Windows represent one of the most complex assemblies for considering both UHI and wildfire impacts. Low solar heat gain coefficient (SHGC) glazing can reduce radiant heat transmission and cooling loads; when combined with multi-pane construction, the assembly improves the envelope’s insulation performance. Tempered or heat-strengthened glass is also preferred in WUI

[55] ASHRAE, EPA, NIST: Planning Framework for Protecting Commercial Building Occupants from Smoke During Wildfire Events
[56] How HVAC Systems Mitigate Wildfire Smoke

applications, as they are more resistant to cracking under conditions of heat exposure. Windows specified within the WUI should also be non-combustible, able to resist embers and ignition.

Shading strategies along windows can also help control indoor temperatures and conserve cooling energy. Shading applied to the exterior of the building is often more effective at controlling indoor temperatures than indoor shades.[57] Exterior shading devices include overhangs, horizontal fins, and exterior roller shades, which can redirect solar gain that would otherwise land on glazing. When constructed from non-combustible materials, they can also partially shield glazing from radiant heat and embers.

Cool Roof and Wall Material Selection

Installing cool roofs and walls is a relatively inexpensive energy conservation measure to passively reduce cooling loads in warmer regions. Cool surfaces reflect sunlight and efficiently radiate heat away from the roof or wall surface. Installing cool surfaces reduces the conduction of heat into the building, reducing the need for air-conditioning in conditioned spaces. This saves energy and money, and the decreased load helps to moderate peak grid demand during heat waves and very hot summer afternoons, thereby reducing the risk of power outages.[58]

Installing cool roofs and walls is one of the most cost-effective passive strategies for reducing cooling loads, which saves energy and money while also reducing peak electricity loads during heat waves. At the city scale, reflective surfaces, including cool roofs and exterior walls, can amplify neighborhood-level cooling. For optimal UHI mitigation, prioritize materials with high solar reflectance and thermal emittance, or Solar Reflectance Index (SRI) values, over standard dark roof materials with a low SRI. Solar Reflectance (SR) refers to the percentage of sunlight a material reflects back into the atmosphere. An SRI is a value that combines solar reflectance and thermal emittance, or the capacity of a surface to absorb heat. SRI values typically fall between 0 and 100.

To address wildfire risks, these roofs may be specified as non-combustible, ignition-resistant assemblies that meet wildfire performance standards such as ASTM E108 or UL 790, which test roof systems for their resistance to external fire exposure, including ember exposure, flame spread, and radiant heat tolerance.[59] Roofing systems are assigned fire ratings from Class A (highest) to Class C (lowest), under standards such as UL 790 and ASTM E108, based on how the entire roof assembly performs in standardized fire tests.[60] Class A-rated roofing systems are typically required in wildfire-prone areas, including under the WUI Code, and are made of non-combustible materials like metal, tile, or concrete.

A summary of typical roof types and their relative performance levels under extreme heat and wildfire conditions is provided below.

57 EPA: Extreme Heat and Indoor Air Quality
58 Lawrence Berkeley National Lab Heat Island Group
59 Everything You Need to Know About Asphalt Shingles Fire Rating
60 Class A, B, and C Roof Ratings, UL

Asphalt Shingles

Under typical conditions, asphalt shingles stand out for their combination of durability, cost-effectiveness, and aesthetic appeal. However, conventional dark shingles usually have a low Solar Reflectance Index (SRI) and are combustible and can morph when exposed to fire conditions, unless specifically treated to comply with Class A criteria. Fire retardants can be applied to the asphalt mixture to improve its fire-resistance performance. Class A asphalt fiberglass composition shingle roofs are one good option for wildfire prone areas.[61]

Cool Asphalt Shingles

Cool asphalt shingles utilize solar-reflective granules to reflect more sunlight and absorb less heat than traditional, dark asphalt shingles. By absorbing less heat, cool asphalt shingles can lower indoor temperatures and reduce energy demand for cooling as well as help mitigate the urban heat island. However, the SRI for cool asphalt shingles will be lower than other cool roof materials.

Metal Roofing

More than 15 percent of roofing installations in the United States are metal roofs, and metal roofs are becoming more popular.[62] Metal roofs, like standing seam shingles, on steep slope buildings offer high durability and relatively longer service lives than asphalt shingles. They typically have relatively a high SRI, and, when paired with appropriate surface finishes, they can also achieve high thermal emittance, or the ability to release or radiate heat; adding a white or reflective coating can further increase both solar reflectance and emittance, helping the roof stay cooler.[63] Metal roofs made from galvanized steel, aluminum, or copper are also non-combustible and can achieve Class A ratings when used in approved assemblies, but the overall rating still depends on the deck, underlayment, and other system components.[64]

Concrete or Clay Tile

Concrete and clay tile roofs offer strong combined benefits for UHI and wildfire resilience. They are non-combustible and able to achieve Class A ratings. Their mass and thickness also offer thermal mass benefits, slowing heat transfer to underlying decking and spaces. Products are also available in light-color or reflective formulations.

Wood Shake or Cedar Shingle

Wood is naturally cool and has a moderate reflectance, meaning that its performance can vary.[65] They also do not have high emissivity, meaning they cannot shed absorbed heat back to the atmosphere. Wood shake and cedar roof shingles perform poorly in wildfire conditions, constituting one of the highest risk roofing types for fire, and are often prohibited by WUI Codes. They are inherently combustible, ignite readily from embers, and can cultivate rapid flame spread across the roof. While some jurisdictions in high fire risk areas ban all treated and untreated wood

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61 Fire-Resistant Roofs
62 Metal Roofing Market
63 A Practical Guide to Cool Roofs and Cool Pavements
64 Understanding Metal Roof Performance Standards & Testing
65 DOE: Cool Roofs

shakes or cedar shingles outright through their WUI code, others require that treated wood shakes and cedar shingles meet specific fire ratings. Wood shake or cedar shingles that have not been treated with fire retardant are either unrated, meaning it does not meet the minimum fire-resistance testing standards or at best receives a Class C.[66] Factory-applied fire retardant treatments of wood shingles or shakes typically qualify as Class B but can qualify as Class A if the roof assembly includes other fire-resistant materials underneath.[67] Additionally, embers can lodge between shakes and reach underlying sheathing. When it comes to solar reflectance, wood is naturally cool and has moderate reflectance, meaning that its performance can vary.[68]

Coatings

Coatings are thick, paint-like surface treatments for mainly low-slope and flat roofs. They are engineered to improve adhesion, durability, biological resistance, corrosion, and dirt shedding, while also functioning as cool roofs on many types of materials. They can be cementitious, elastomeric, or silicone or acrylic paints, which all offer high initial solar reflectance and thermal emittance. Applying cool roof coatings can increase a roof's SRI, help lower surface temperatures, and contribute to reducing urban heat island effects.[69] In a fire, these coatings can contribute to roof system performance, because fire-retardant additives and formulations help slow flame spread.[70,71]

Single-Ply Membranes

Single-ply membranes are prefabricated sheets installed in a single layer on low-slope roofs. They are typically adhered or mechanically fastened across the roof surface, with seams sealed using tape, adhesives, or welding. They are also used for extensive repair of existing buildings. Many manufacturers produce them with reflective "cool roof" options. Similar to coatings, single-ply membranes can be formulated to improve the fire-resistance of the roofing system. Common types of single-ply membranes include:

- EPDM (ethylene propylene diene monomer): A synthetic rubber membrane with seams that are typically glued or taped together.
- CSPE (chlorosulfonated polyethylene): A polymer-based membrane with seams that can be heat-welded.
- PVC (polyvinyl chloride), TPO (thermoplastic polyolefin), and KEE (ketone ethylene ester): Thermoplastic membranes with seams that are welded to form durable, watertight joints.[72]

Film or Panels With Film

Films are thin polymer sheets that are adhered or laminated to a substrate and can be engineered to modify the thermal behavior of a roof assembly.[73] Their composition and configuration vary according to functional objectives and climatic conditions. For instance, films developed for UHI

66 Wood Shake Roofing Characteristics and Considerations
67 Fire Retardant Wood Shingles or Shakes
68 DOE: Cool Roofs
69 Reducing Urban Heat Islands: Compendium of Strategies Cool Roofs
70 How Roof Coatings Enhance Fire Resistance in Commercial Roofing
71 Reducing Urban Heat Islands: Compendium of Strategies Cool Roofs
72 Reducing Urban Heat Islands: Compendium of Strategies Cool Roofs
73 Roofing Films, AM Stabilizers

mitigation are formulated to enhance surface solar reflectance and thermal emittance, which may include retroreflective (RR) materials or polyvinyl fluoride (PVF)-based films.[74,75,76] However, films can inherently be combustible and may not withstand wildfire exposure or achieve Class A fire ratings on their own. Thus, coatings (or fire-rated membranes), which can provide fire resistance benefits as part of a tested roof assembly, are often preferable.

TABLE 5: SUMMARY OF AVAILABLE ROOFING PRODUCTS AND THEIR UHI AND WILDFIRE PERFORMANCE

Product Type	UHI Performance	Wildfire Performance
Dark, Low-Albedo Asphalt Shingles	• Conventional dark shingles have low Solar Reflectance Index (SRI).	• Naturally combustible and can change form under fire exposure. • Adding fire retardants to asphalt mixture to improve fire resistance and performance. • Opt for Class A asphalt fiberglass composition shingle roofs.
Cool Asphalt Shingle	• Cool roof coatings can increase roof's SRI, lowering surface temperatures and UHI. • Solar-reflective granules added to shingles to reflect more sunlight. • Achieves higher SRI than dark asphalt shingles but still lower than clay or concrete tiles and coated metal.	• Naturally combustible and can change form under fire exposure. • Adding fire retardants to asphalt mixture to improve fire resistance and performance. • Opt for Class A asphalt fiberglass composition shingle roofs.
Metal Roofing	• Relative high SRI and thermal emittance. • Adding a white or other reflective coating can further increase SRI and emittance.	• Metal roofs made are non-combustible and can achieve Class A ratings.
Concrete or Clay Tile	• High thermal mass and vented tiles can reduce heat transfer to inside of buildings. • Natural cool colored clay tiles or light-colored concrete tile options available or select a factory-applied or retrofitted cool-colored glaze for clay tiles or coating for concrete tiles.	• Non-combustible and generally more resistant to direct flame and high temperatures. • Products are available in light-colored or reflective formulations.
Wood Shake or Cedar Shingle	• Naturally cool material though reflectance may vary. • Do not have high emissivity. • Do not maintain high reflectance in initial vs. aged ratings.[77]	• Naturally cool material though reflectance can vary. • Perform poorly in wildfire conditions. • Often prohibited by WUI Codes.
Coatings	• Typically cementitious, elastomeric, and silicone coatings or acrylic paints, both offering high initial solar reflectance and thermal emittance, which helps keep roofs cooler.	• Fire retardant additives and formulations help slow flame spread.
Single-Ply Membrane	• Many manufacturers produce them with reflective "cool roof" surfaces.	• Can be formulated to improve fire resistance of the roofing system.

74 Retro-reflective surfaces for mitigating urban overheating: application, evaluation, and optimization
75 Radiative cooling improvement by retro-reflective materials
76 Tedlar® PVF Film
77 CCRC Initial vs. Aged Ratings

Product Type	UHI Performance	Wildfire Performance
Film or Panels With Film	• Films can be developed for UHI mitigation by enhancing surface solar reflectance and thermal emittance.	• Can be combustible and may not withstand wildfire exposure or achieve Class A fire ratings on their own. • Fire-rated membranes that provide fire resistance benefits are available.

Implementation Models

Building Code Updates

Building codes can accelerate adoption of best practice resilience strategies. Currently, UHI and wildfire code provisions are written separately from each other and are often addressed in different codes and through different planning efforts. For example, many cities adopt the WUI Code by reference to their local building code, fire code, or development regulations. Whereas many cities are only now trying to address UHI in a more holistic way, aiming to align and integrate goals and actions in disparate city-level plans into zoning or city-wide ordinances. However, building codes have the potential to serve as the place where conflicting performance objectives are reconciled at the building scale, by including comprehensive requirements for assemblies, material choices, and other design strategies that meet both heat- and wildfire-mitigation criteria. As jurisdictions update their codes, they can incorporate multi-hazard performance pathways—for example, specifying materials, ventilation strategies, and envelope requirements that simultaneously address cooling loads, smoke intrusion, and ignition resistance—ensuring that resilience measures work together, and in the appropriate areas, rather than in isolation. The Cool Roof Rating Council (CCRC) maintains a list of codes, standards, and voluntary programs that promote cool roofs, which may be accessed here. The Smart Surfaces Coalition and the Sabin Center for Climate Change Law provides model local ordinances, policies, and best practices designed to mitigate urban heat island effects and manages a database of codes from across all 50 states related to extreme heat.

Spotlight: California

California's Title 24 (CALGreen) addresses urban heat and wildfire through separate provisions. Part 6 of the code includes requirements for cool roofs, shade structures, high-albedo hardscapes, landscape efficiency, and others. Roofing products must be certified as a cool roof or meet prescriptive reflectance and emittance requirements. Chapter 7A covers fire resilience, including ignition-resistant construction, ember-resistant vents, and defensible space vegetation. A building that is located in a high fire hazard severity zone as well as a hot climate zone would be required to comply with both sets of requirements.

Weatherization Programs

Weatherization programs offer support for conducting energy audits, prioritizing measures by cost-effectiveness, and coordination installation of insulation, air sealing, window and door upgrades, heating and cooling system replacements, and health and safety improvements.

These programs are often federally funded and administered through state energy offices or local agencies. The US Department of Energy's Weatherization Assistance Program (WAP) funds local weatherization crews who conduct these energy assessments and execute measures to increase the efficiency and safety of eligible homes. The Low Income Home Energy Assistance Program (LIHEAP), administered by the US Department of Health and Human Services (HHS), also provides eligible households with energy assistance, including financial assistance for weatherization. States with relevant programs may allocate 15 percent of their total LIHEAP funds toward weatherization.[78] In addition to WAP and LIHEAP, state utility energy efficiency programs support weatherization.

Spotlight: Austin, Texas

Austin is one of the leading cities that has adopted the WUI code while also running robust weatherization rebates and assistance through Austin Energy.[79] Austin's weatherization programs provide insulation, air sealing, duct repair, and HVAC upgrades for low-income households. Austin Energy also integrates cool roofs into its Green Building Program, which awards points for reflective roofing and high-performance envelopes.[80] This makes Austin a strong example of multi-hazard resilience, even though wildfire and heat are still addressed through separate programs.

Cool Roof Programs

Cool roof programs can operate through a range of mechanisms including utility rebates, direct installation, and contractor certification and training. Utility rebate programs can subsidize the incremental cost difference between conventional and qualifying reflective roofing products, making cool roofs more cost-effective for building owners. These programs are often funded through ratepayer charges or state energy efficiency financing. Direct installation programs deploy cool roof installations to heat-vulnerable populations who are least able to finance upgrades. Contractor certification and training programs focus on building workforce capacity to specify, procure, and install cool roofs. Many cities, including New York, Chicago, Los Angeles, Phoenix, and San Antonio also have programs to apply cool roofs or road surfaces.

78 LIHEAP
79 Austin Energy: Weatherization Assistance
80 Austin Energy Green Building Pre-Submittal Worksheet

Spotlight: Los Angeles, California

Los Angeles City and County have taken a comprehensive, multi-sector approach to promoting cool roof and other heat mitigation interventions across the county, including utility rebates, direct installation programs and workforce training. The LA Department of Water and Power (LADWP) offers utility rebates for reflective materials; the city has also piloted direct installation programs to provide cool roofs to low-income households located in heat-vulnerable neighborhoods.[81,82] The city and county have also been responsible for partnering with nonprofits and workforce development programs to coat tens of thousands of square feet of rooftops as well as streets, schoolyards, and parking lots in cool materials. Contractor training and certification are also supported by city investment to ensure correct installation of reflective materials.[83]

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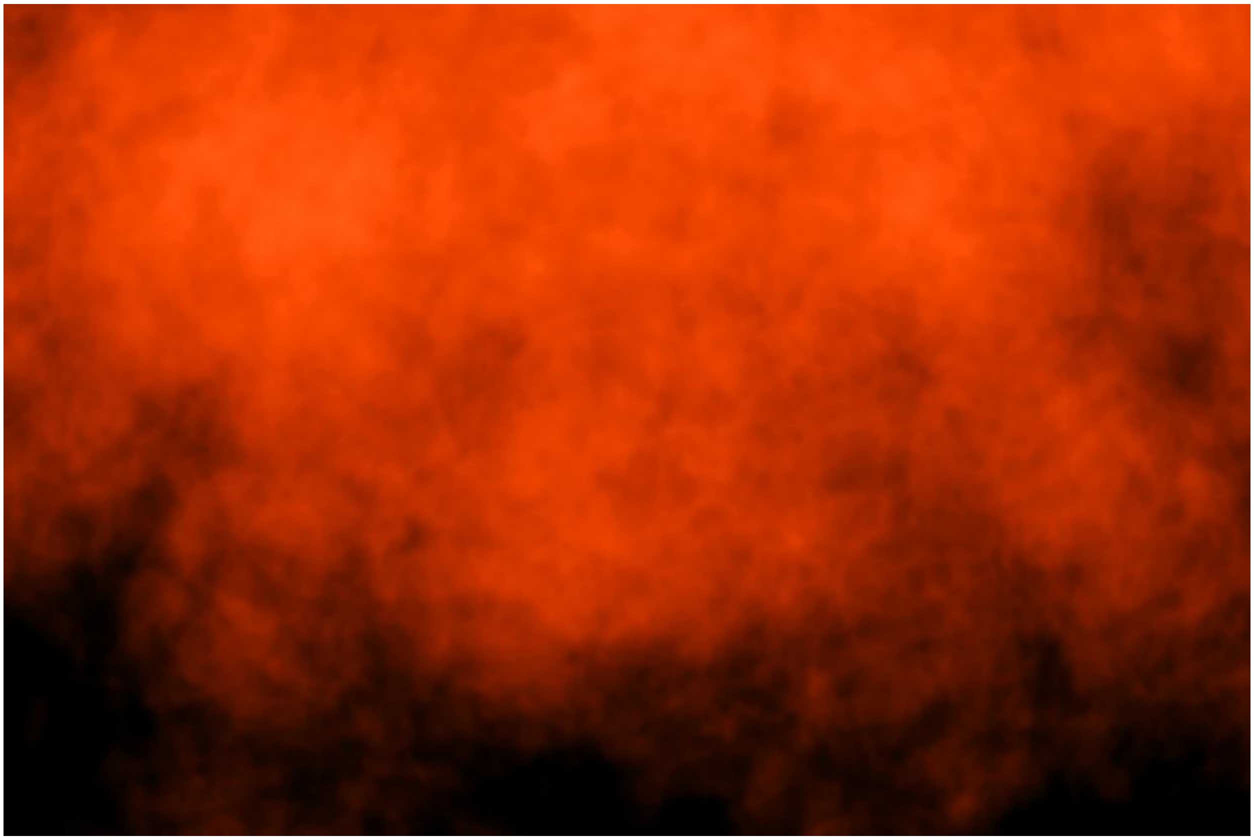
81 LADWP: Cool Roofs

82 Los Angeles: Energy Efficiency Conservation Block Grant

83 Cool Roof Trainings



New Buildings Institute (NBI) is a nonprofit organization driving better energy performance in buildings. We work collaboratively with industry market players—governments, utilities, energy efficiency advocates and building professionals—to promote advanced design practices, innovative technologies, public policies and programs that improve energy efficiency and reduce carbon emissions. We also develop and offer guidance and tools to support the design and construction of energy efficient buildings. Learn more at newbuildings.org.